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Procedia Engineering 121 (2015) 1741 – 1748

Procedia Engineering

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9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Real Operation Pattern of District Heating System and Its Heating Effects

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Abstract

A field study has been carried out for one district heating system in Beijing. According to the surveyed data, operation pattern of the district heating system has been discussed and quantitative relationship between supply water temperatures with outdoor temperatures has been developed. It indicates a fine linear correlation of daily temperature of supply water with weighted outdoor temperature within three days and an operation condition of "large flow rate and small temperature difference". Additionally, the effects of the operation pattern on energy consumption and indoor air temperature have been presented. Results show that the heat supply of this heating system couldn't meet the exact requirements for different rooms and at different time, and failed to build a stable indoor thermal environment in terms of space and time.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: District heating system; Operation pattern; Supply water temperature; Outdoor temperature; Heating Effects

1. Introduction

In recent years, the energy consumption per square meter for space heating has been reduced because of the improvement of the insulation level and air tightness of building envelopes. However, with the rapid growth of the building construction, energy conservation for space heating in northern cities of China has still been an important issue to address.

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.146

In northern cities of China, heating system has been dominated by the type of district heating, which accounts of about 80% of contribution to space heating in terms of area. In this system, the supply water is heated to a certain temperature by heat source as boiler and then delivered to end users as radiators through pumps for space heating. In this way, the energy consumption of district heating system includes one part to heat rooms and the other part for water cycle between boilers and radiators. So the operation pattern of district heating system in terms of water flow rate and temperatures of supply and return water will have a significant influence of energy consumption of the system. Consequently, there is still deep research needed for the operation pattern of district heating system to study its impacts on energy consumption and indoor thermal environment so as to find the potential of heating energy saving in northern cities of China.

In order to reduce energy consumption of district heating system and provide comfortable indoor thermal environment simultaneously, many control strategies have been introduced to adjustment of water flow rate and temperatures of supply and return water. Climate compensator is one kind of device to identify how to adjust water flow rate and water temperature along with outdoor climate conditions on the basis of heat balance principle. This device had once been widely introduced to many district heating systems. However, it usually failed to achieve what has been expected for energy use and indoor air temperature due to the thermal inertia of buildings and the different thermal requirements of occupants. For this reason, the district heating system has currently had to operate in the pattern of “fire with climates” ac-cording to operators’ experiences.

To summarize, there is still a lack of a clear and adequate understanding about the quantitative relationship between heat supplies of district heating system with outdoor climate conditions, which limits the ability to decide the proper control strategy to minimize the energy consumption of district heating system. In the present study, a field study has been carried out for one district heating system in one university in Beijing. Hourly data of water flow rate, supply water temperature, return water temperature, indoor and outdoor air temperatures, as well as daily gas consumptions have been measured and collected. Moreover, occupants’ thermal sensations have been reported in three dormitory buildings. According to the field study data, operation pattern of the district heating system has been discussed and quantitative relationship between supply water temperatures with outdoor temperatures has been developed. Additionally, the effects of the operation pattern on energy consumption and indoor air temperature have been presented.

2. Methods

The district heating system in this study has been served for space heating of some dormitory buildings, office buildings, laboratory buildings and residential buildings in one university in Beijing, with a total heating area about 140000m^2. The farthest building in the heating area was about at a distance of 350m from the boiler room. The system diagram is shown in Figure 1 (a).

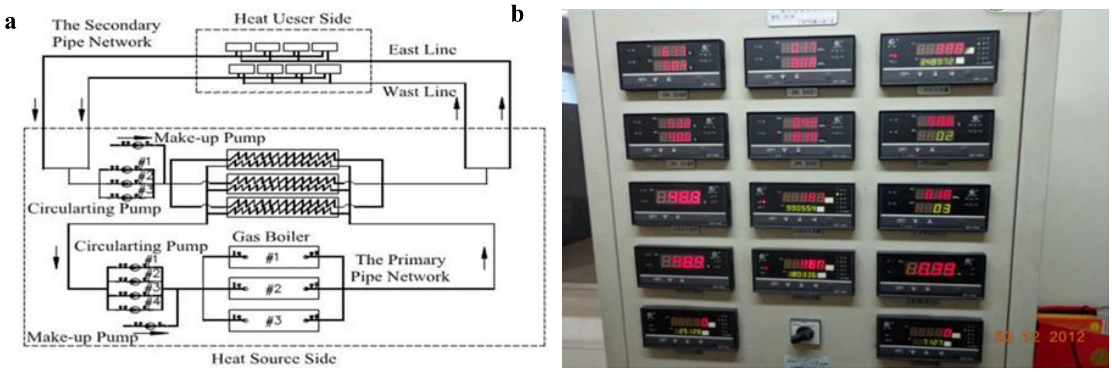

Fig. 1. Physical constitution of system (a) System diagram; (b) Monitoring device.

In this district heating system, the heat source side (boilers) was connected with the end users (radiators) through plate heat exchangers. The water in the primary pipeline is heated by boilers and then transported to the plate heat exchanger by the primary pumps, where the heat will be transferred to the secondary pipeline. With the operation of the pumps in the secondary pipeline, the water is circulated between the plate heat exchanger and the radiators for space heating.

The monitoring device of the system, as shown in Figure 1(b), can record the parameter of the operation condition of the system, including hourly temperatures of supply and return water, the water flow rates of the primary and secondary pipelines, as well as the daily electric powers of the pumps in the pipelines. The daily gas consumption can be read from the gas meter. The hourly data of outdoor temperature and solar radiations can be obtained from out-door weather stations.

3. Results

3.1 The variations of water flow rates

For the district heating system in this study, its operation has been implemented manually by professional operators. The flow rate of supply water in the primary pipeline differed in two periods of the whole heating season. For the primary pipeline, only one boiler and one pump were operated in the early and later heating season, and the flow rate was 200m3/h. The water flow rate increased from 200m3/h to 400m3/h in the middle of the heating season, with two boilers and two pumps in operation. For the secondary pipeline, the water flow rate was constant at 650m3/h throughout the whole heating season, with two pumps in operation.

3.2 Variations of water temperatures

Hourly variations of supply water and return water temperatures of the primary and secondary pipelines during the whole heating season are shown in Figure 2.

3.3 Variations of system operation with outdoor temperatures

According to what the operators reported, the supply water temperature has been adjusted by regulating the gas consumption depending on the outdoor climate conditions. The relation-ship between the daily gas consumption and the daily mean outdoor temperature is shown in Figure 3. Moreover, the relationships between the supply water temperature for the primary and secondary pipelines with the average daily outdoor temperatures are shown in Figure 4.

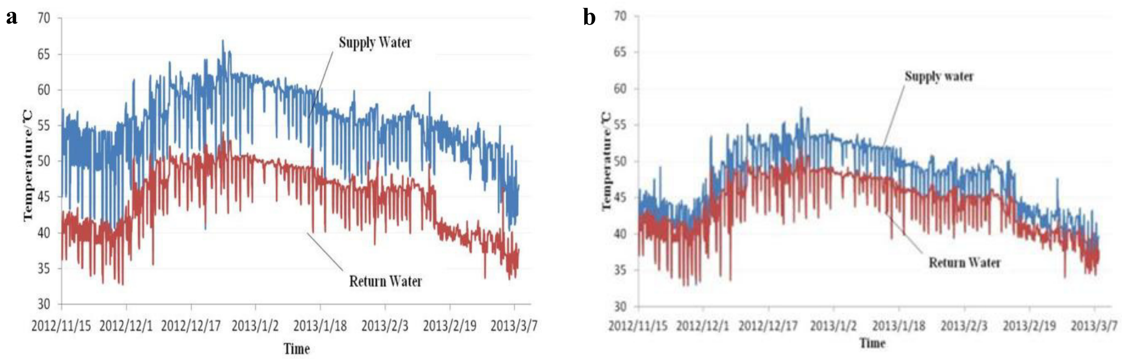

Fig. 2. Variations of supply and return water temperatures (a) The primary pipeline; (b) The secondary pipeline.

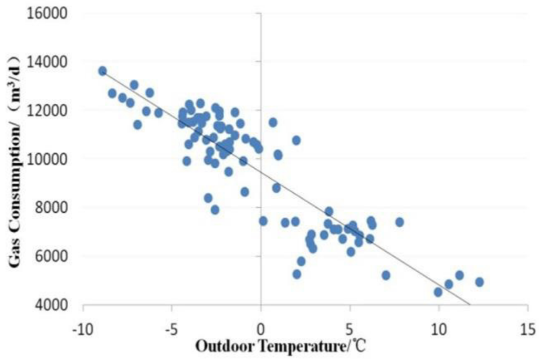

Fig. 3. Relationship between daily gas consumption and average daily outdoor temperature

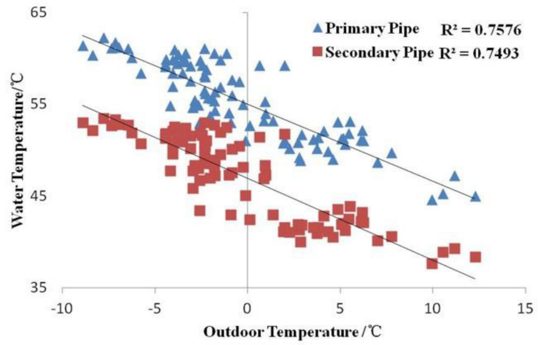

Fig. 4. Relationships between supply water temperatures and average daily outdoor temperature

It is clear that the daily gas consumptions almost fit well with the average daily outdoor temperatures in a negative linear way, with a correlation coefficient of 0.88. Therefore, the daily gas consumptions have been mainly determined by the outdoor temperatures.

Using linear regression analysis, the correlation coefficient of the average daily temperature of supply water for the primary pipeline with the average daily outdoor temperature has been calculated as 0.76; and that for the secondary pipeline as 0.75. These statistical results indicate that the linear correlation between supply water temperatures and outdoor temperatures are not significant. Analyzing the thermal process through buildings, the above insignificance has been due to the thermal inertia of building envelopes. So the time delay and temperature decay should be considered. As a result, the relationship between weighed outdoor temperatures within three days (the weight coefficient for the current day, the previous day and the two days before being 0.5, 0.3 and 0.2, respectively) and the average supply water temperatures of the current have been discussed and presented for both primary pipeline and secondary pipeline, as shown in Figure 5.

The correlation coefficients of the weighted outdoor temperatures (T_w) and average daily supply water temperatures for primary pipeline (T_{g1}) and secondary pipeline (T_{g2}) are calculated as 0.83, 0.84, respectively. It indicates the improvement of linear correlations of T_{g1}、T_{g2} with T_w. The variations of average daily supply water temperatures with weighted out-door temperatures can be expressed as the follow two equations for both primary and secondary pipelines.

$$T_{g1} = -T_w + 54.82 \quad (1)$$

$$T_{g2} = -T_w + 46.79 \quad (2)$$

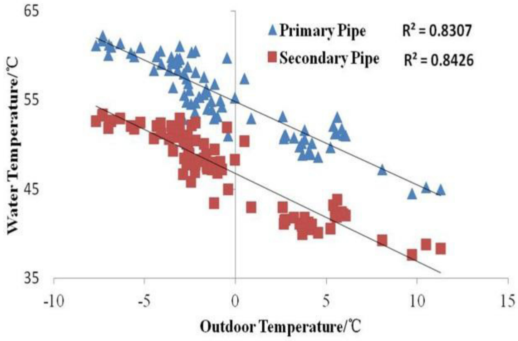

Fig.5. Relationships between supply water temperatures and weighted outdoor temperatures every three days

3.4 Variations of system operation with daily schedule

Further research for the operation pattern has been done at a daily scale. There are two typical patterns concerning the hourly variations of supply water temperatures, as shown in Figure 6.

For the Pattern One, which occurred on when the outdoor weather became very cold with the minimum temperature even smaller than -8℃, the supply water temperatures remained high and stable excluding in midnight, when the occupants sleeping schedule has been considered. A temperature reduction of 5-7℃ for supply water in primary pipeline and that of 3-5℃ for secondary pipeline can be seen in midnight (0:00-4:00). For Pattern Two, which occurred on when the outdoor temperatures were larger than 1℃, supply water temperature de-creased both in midnight and in the noon (12:00-15:00), with temperature reductions of 6℃ for primary pipeline and 3℃ for secondary pipeline in midnight, and about 5℃ and 2℃ in the noon.

3.5 Energy consumptions and indoor thermal environment

Using the collected data of daily gas consumption, the energy consumption equivalent to standard coal per square meter can be calculated as 11.36kgce/(m^2•a). Moreover, by summarizing the power consumptions of all the pumps in the two pipelines, the energy consumption for pumps is calculated as an equivalent value of 0.74kgce/(m^2•a) to the standard coal during the whole heating season. Accordingly, the total energy consumption per square meter of the district heating system is about 12.1kgce/(m^2•a), in which the energy consumed by pumps accounts for approximately 6%. In comparison with the average energy consumption for space heating for northern cities of China in 2013, which was about 16.4kgce/(m^2•a), it can be briefly seen that the district heating system in the present study was operated in a relative high energy efficiency pattern in 2013.

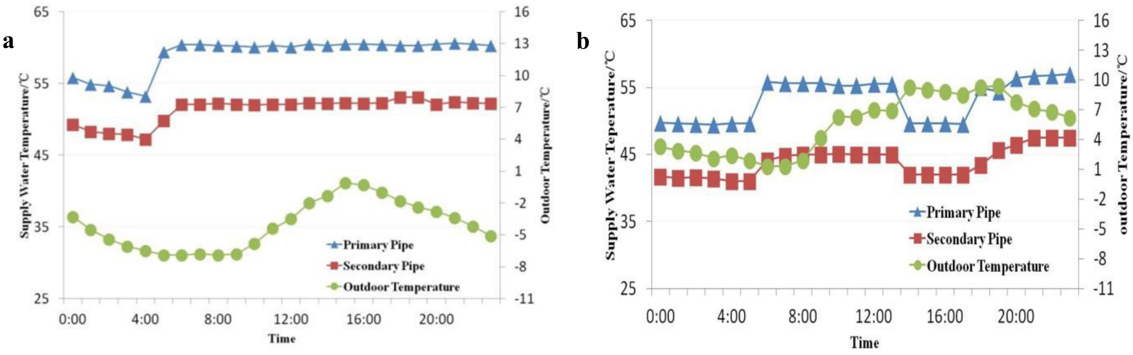

Fig. 6. Two typical patterns of supply water temperatures (a) Pattern one; (b) Pattern two.

One south face room and one north face room on middle floor of one dormitory building, which is located near the centre of heating area, have been selected to conduct field measurements of indoor air temperatures at an interval of 10 minutes using temperature data logger. The average daily temperatures for these rooms together with that of outdoors on January are shown in Figure 7(a).

As shown in Fig. 7, there is a significant difference of about 4℃ of indoor air temperature between the two rooms. Additionally, the indoor air temperatures for the two rooms have varied obviously with time, with a temperature difference between the maximum and the mini-mum reaching to 3℃.

Moreover, a questionnaire study has been carried out in three dormitory buildings, which are located at different distances from boiler room, to ask the occupants to report their thermal sensations during the whole heating season. In this study, 279 effective samples have been used and the results of occupants' thermal sensations in the three dormitory buildings are shown in Figure 7(b).

In the three dormitory buildings, most occupants feel comfortable about the indoor thermal environment; some of them even feel hot. However, there are still some occupants who feel cold and have been dissatisfied with indoor thermal environment. Such dissatisfactions in-creased with the distances between the building and the boiler room, and are reported by occupants to result from the cold surfaces of radiators in their rooms. Therefore, the results of questionnaire have consolidated the demonstration of uneven spatial distribution of indoor thermal environment.

4. Discussion

Based on the field survey data, the supply water temperature profiles have been developed in this research. The variations of supply water temperature indicate the significant influences of outdoor temperatures on operation patterns of district heating system. Generally speaking, the supply water temperature falls when the outdoor temperature rises. Additionally, the life-styles of occupants have also been taken into account by system operators when determining the operation patterns.

As for the temperature level of supply water of the heating system, it can be seen that the district heating system has not been operated on the design condition, which indicates the set points of supply and return water temperatures as 75/50℃. Moreover, the temperature differences between the supply and return water for the primary and secondary pipelines were far below the design value of 25℃. In this sense, the district heating system in this study has been operated on the condition of "large flow rate and small temperature difference".

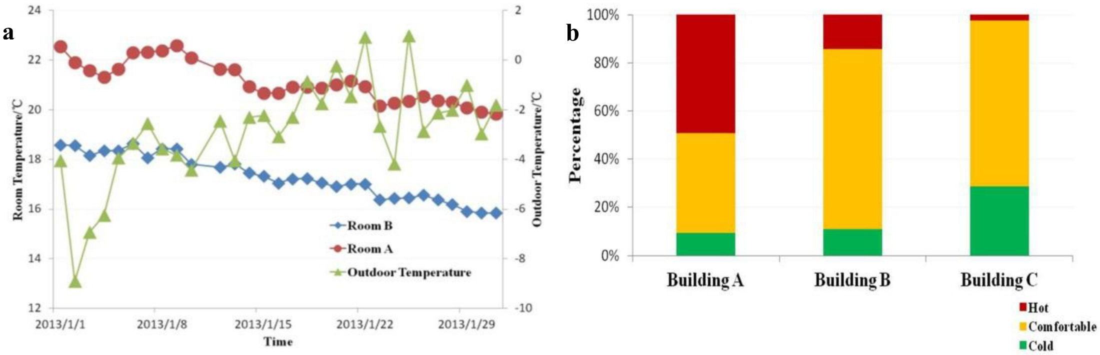

Fig.7. (a) Daily indoor and outdoor temperatures; (b) Occupants' thermal sensations in three dormitory buildings.

With the energy consumption of the heating system for the whole heating area during the whole heating season and indoor air temperatures of two rooms, what can be drawn is the primary understanding about the effects of operation patterns. However, the quantitative relationship between operation patterns and heating effects (energy use for each radiator and indoor air temperatures) has not been discussed and analyzed in this research, which limits the ability to illustrate to what extent the operation pattern of heating system can influence energy consumption the heating system and indoor thermal environment, and thereby to find the solutions of improving operation pattern of district heating system.

A further investigation of quantitative effects of operation patterns on room air temperatures and heat release by radiators in each room and their variations with building forms would be interesting in a future study.

5. Optimization of operation pattern

This research gives us a picture about the real operation pattern of district heating system. The results show that the current operation pattern of district heating system still need to be improved in terms of its heating effect.

In order to minimize the energy consumption of heating system, avoid overheating during early and later heating season, and build the almost same indoor thermal environment for all the rooms with different building forms, a further research should be carried out to optimize operation pattern by comparing the heating effects between different operation patterns of district heating system. In this way, the algorithm of optimization of supply water profile will be developed for a specific building in a specific climate zone.

6. Conclusions

Under the manual control, the district heating system has been operated on the condition of "large flow rate and small temperature difference", which is far away from the set points of supply and return water temperatures as 75/50℃. And there is a fine linear correlation of daily temperature of supply water with weighted outdoor temperature within three days. For this operation pattern, the energy consumption for space heating is relatively small in comparison with other heating systems, but the uneven distributions of indoor air temperatures are significant in terms of space and time.

This research can help designers have a better understanding about the real operation pat-tern of district heating system and its problems, which is useful for improving design in the future.

Acknowledgements

This research was undertaken as a part of the project supported by the National Natural Science Foundation of China (Grant No. 51278004) and by Beijing Key Lab of Heating, Gas Supply, Ventilating and Air Conditioning Engineering (Grant No. NR2012K07).

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